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REVIEW ARTICLE

Application of landscape ecology to the research on wetlands

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Abstract: This review describes the characteristics and hot spots of wetland research, including biodiversity protection of wetland, management and restoration of wetland, function and process of wetland, and the theories, methods and scales of landscape ecology. Moreover, some deficits of landscape ecology theory and method were discussed, and the application of landscape ecology to research on wetlands was reviewed specially, involving in the application of landscape structure principle, landscape pattern, and scale and hierarchy theory. In conclusion, landscape ecology plays an enlightening and guiding function on the comprehensive research of wetlands at multi-scales.

Keywords: wetland; landscape ecology; landscape structure; landscape pattern; scale and hierarchy

Introduction

Wetlands have been proved to be useful to humans for their functions. As the transition zone of terrestrial systems and water systems, wetlands have the characteristics of both systems. Surface ponding or soil saturation, waterlogged soil, anaerobic conditions and the plants and animals adapting to the moist environment are the essential features that make wetlands different from land system and water system. Wetland environment forms and preserves a large number of fossil fuels we rely on now. Meanwhile, wetlands are known as “biological supermarkets”, supporting large food chain, rich biodiversity, unique habitat for large number of wildlife, and rich genetic materials. They are also known as “the kidneys of the Earth” and have the function of pooling water and sequestering pollutants. Besides, Wetlands can stabilize the water supply, purify sewage, protect coastal line and recharge groundwater (Lu 2001, 2002; Mitsch & Gosselink 2000; Yuan and Lu 2004; Tong et al. 2002; Yuan 2001). As the “sink” of carbon dioxide as well as the climate “stabilizer” at the scale of globe, wetlands play great significance in the research of global environmental change. Costanza et al. estimated that the coastal areas and wetlands ecosystem provided total 1.5575 billion US dollars service value, accounting for 46% of service value of global ecosystem (Costanza et al. 1997). There is a growing convergence belief that wetlands are a vital ecosystem providing considerable social, economic and environmental interests for the globe (Yuan 2001).

In recent years, however, excessive development and utilization makes the quantity and quality of wetland sharp decline. Accordingly, it exhibits that the wetland area is shrinking, the storage function of water resource is declining, the river runoff is reducing and the groundwater line is lowering. Subsequently, wetland function degradation leads to habitat destruction, biodiversity reduction and climate dry. Furthermore, soil is degrading and soil fertility depletes; the pollution of wetlands is intensifying and siltation is becoming increasingly serious (Wu and Lu 2005; Wang et al. 2005; Bai and Wang 2003). As scholars and policy-makers attach more importance to these issues and raise public awareness about the importance of wetland function, the key point of the study on wetland is shifting from resources survey to natural process of wetlands and then to reveal the changes of function (Lu 2002, 2005; Yang 2002). Concerning the wetland type, the research on wetlands has extended from single type of marsh to various types of wetlands. As far as the content, scholars do not just consider wetlands as the habitats of waterfowl but as integrated organism with more function (Lu 2005; Yang 2002; Wang et al. 1997). According to the direction of international wetland science and the requirement of ecology and environment safety, the key points of the study on wetlands is about the wetland process such as the hydrology process and accommodating function, biogeochemical cycle of wetlands, the quantitative evaluation of wetland function and the effect of land usage on wetlands, the standard and technique of wetlands restoration (Lu 2005).

And all these key points provide opportunity for the application of landscape ecology to the research on wetlands. The contents and scale of landscape ecology are in line with current research priorities of wetlands.

Based on ecology framework and absorbing the elites of modern geography and system science, landscape ecology is an ecology branch that devotes to study the spatial structure, interaction, coordination function and process of the integer (landscape) composed by many different ecosystems (Turner et al. 2001; He et al. 2003). Forman and Godron (1986) pointed that landscape

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structure, function and dynamics was the basic content of landscape ecology. Xu (1996) also considered that landscape ecology is to research the landscape planning and management which establishes the planning and programming of landscape restoration, protection, construction and fixed on the corresponding goal, measures and policies. Comprehensive integrity and landscape heterogeneity is the core idea of landscape ecology as well as where its vitality lies. Heterogeneity was the important characteristics of landscape system, indicating its complexity and variability. And it includes temporal and spatial heterogeneity. Xiao et al. (1997) pointed that space heterogeneity was the core of landscape ecology and usually included space component and space configuration, the former referring to the variety of type, quantity and area proportion of landscape components (ecosystem) and the latter referring to the spatial distribution, the shape and size of patch, contrast and connectivity of landscape. Landscape ecology emphasizes the theory of spatial ecology, mainly including scale, spatial pattern and mosaic dynamic and focusing on the maintenance and development of spatial heterogeneity (Xiao et al. 1997). One of the aims of landscape ecology is biodiversity conservation and the maintenance of ecological stability. Another point of the vitality of landscape ecology is that it directly extends to human and management system and pays attention to the effect of human on ecology (Xiao et al. 1997). Furthermore, the scale of landscape ecology is most suitable for planning and management because landscape has obvious borderlines and common characteristics.

Application of landscape ecology to research on wetlands

Application of landscape structure principle to research on wetlands

Landscape is a heterogeneous integrity composed of patch, corridor and matrix, which can be considered as ecosystem mosaic. For wetland landscape, the heterogeneity of this mosaic is dominated by species, gene, energy, nutrition and flow of water, of which water is the key element.

A perfect landscape structure is a coarse grain landscape composed of many fine grain landscapes that can provide the most appropriate ecological interest and certain resources and environment (Bridgewater 2007). In most circumstances, referring to landscape, human being is often not taken into consideration but it is an important element of landscape. Landscape heterogeneity plays a very important role in the management and protection of wetlands, indicating the variability and complexity of landscape composition. The heterogeneity of landscape structure is vital for the subsistence and biodiversity of hydrobiology. In addition, buffer zones and ecotone play an important role in building a landscape heterogeneity structure.

Take the research on the habitat of turtles for example. The study site is located at Booderee National Park, a 7000 ha^2 reserves located within the Commonwealth Territory of Jervis Bay in southeast Australia. Using radio-telemetry, Roe and Georges (2007) examined terrestrial habitat use and movements of 53 eastern long-necked turtles in an area of Southeast Australia characterized by spatially diverse and temporally variable wetlands. They found that the majority (95%) of individuals used sites within 375 m of the wetland and that turtles were also associated with more than one wetland, using permanent lakes during droughts and moving en masse to nearby temporary wetlands after flooding. It can be inferred from the above study results and the literature review that movements between wetlands allow individuals of several species to conduct many essential behaviors and such movements likely continue even if long distances must be traversed. And we can also argue that the management schemes directed at wetlands as individual units with only narrow terrestrial buffer zones would not adequately capture the mosaic of habitats for this species. Wide terrestrial buffer zones in wetland management may denote an important shift in focus from wetlands as isolated patches to a more inclusive definition of what constitutes core habitat for wetland wildlife.

In recent years, an in-depth study on wetland landscape is conducted based on GIS, one part of which based on landscape type classification, applying ecological theory and using spatial analysis methods to reflect the space-time change of landscape structure with landscape structure metrics (Wang et al. 2005; Bai and Wang 2003; Li et al. 2005). Generally these structure metrics are the area, the number of classes, proportion of dominant class, number of polygons, polygon size variance and elevation range. The driving force and the impact on wetland function were analyzed by studying the change of these metrics. The general conclusions of these studies are that the land use is the leading force of landscape structure change and reverse succession and degradation of wetland ecosystem in the process of land use, and wetland drainage are the internal factors (Fox et al. 1995; Liu et al. 2004, 2005; Zhang et al. 2007).

Further study on landscape structure is focusing on the process of landscape fragmentation, the core of landscape ecology and landscape protection. Landscape fragmentation has a direct impact on some ecological characteristics and the processes such as the landscape biodiversity, energy flow, material recycling. Landscape fragmentation is the process that landscape is separated from consecutive integrity to inconsecutive patches isolated geographically (Liu et al. 2005, 2007; Zhang et al. 2007). Landscape fragmentation is a continuous process, therefore, patch and matrix are generally considered as the basic study elements. An in-depth understanding of this process requires exploring the fragmentation process of patch unit and spatial structure and the impact of human activities. The quantitative analysis method of landscape fragmentation is based on patch broken metrics such as landscape patch density, landscape shape fragmentation, landscape area habitat fragmentation, border density, patch isolation, landscape connectivity and so on. The patch unit fragmentation reflects the area loss and the degree of shape change while the structure fragmentation represents the change of patch spatial composition and the patch-type heterogeneity. Liu et al. (2004, 2007) analyzed the fragmentation process over past 50 years in Sanjiang Plain. The results indicated that patch unit and spatial structure fragmented greatly. As regards patches, the area of maxim patch and the average patch declined and the fragmentation indices of patch shape increased dramatically. Area fragmentation indices of landscape inner habitat increased greatly. Concerning spatial structure, the wetland landscape became riparian landscape from the initial matrix. Meanwhile, the number of isolated wetland patch and the degree of isolation increased with the gradual expansion of farmland. The wetland landscape

fragmentation changed from a landmass and island model to a satellite model, and finally to fully completely isolated model, indicating the great changes in spatial structure of wetland in the Sanjiang Plain. The dominant factor leading to landscape fragmentation is agricultural development, reflecting the tremendous impact of human activities on wetlands.

Landscape fragmentation leads directly to the loss of aquatic lives and threats wetland biodiversity. As certain species can only survive in a specific wetland habitat, the loss of some specific habitats would inevitably result in the extinction of these species. A typical example is shown as the impact of fragmentation of landscape on the habitat of Oriental White Stork (Liu et al. 2006). A habitat suitability index (HSI) model reflecting habitat factors and human impacts at landscape scale were built in the above study. Based on maps of detailed vegetation types in 1960s, 1970s, 1980s and 2004, each habitat factor map was made by uniting vegetation map through GIS technique, and seven units in the model were considered, including human disturbance, food richness, water regime in wetland, vegetation shelter type, distance from road and residential area, the smallest breeding area and the best suitable area, distance from food area to nest area. Results documented that the suitable habitat quality for Oriental White Stork declined significantly in the last 40 years. The total area of wetland reduced 87% and two important habitat type of Oriental White Stork (Carex lasiocarpa marsh and reed marsh) and 95% open water area were completely lost. The reason is mainly attributed to the change of habitat types and fragmentation of landscape occurred in the study area. We also argue that the decrease in patch number such as island—like forest wetlands and their geographical isolation by human destruction have significant effects on habitat quality and species population for Oriental White Stork. Löfvenhaft et al. (2004) studied the biotope patterns over time and spatial-temporal distribution patterns of amphibians in Stockholm in the process of wetlands and urban fragmentation. They found that temporal distribution of amphibians was negatively related to increased fragmentation of valuable biotope configurations. The study also evaluated the relative role between spatial and temporal configuration of amphibian, general biotope loss and degradation as causes for species decline from landscape ecology view. And they applied the results of assessment into the protection of biodiversity and landscape planning (Löfvenhaft et al. 2004). The importance of this paper is not only in the role to protection of biodiversity but also in that it is a trans-disciplinary paper integrating many disciplinary knowledge such as ecology, geography, GIS and so on, and this can provide references for other studies.

Application of landscape pattern theory to research on wetlands

The study on the relationship between spatial pattern and ecological process is a fundamental approach of landscape ecology. It is known that landscape pattern is more easily seized than landscape process and function. Thus it is practical to establish the ecological model between landscape pattern and landscape ecological process and further forecast the basic characteristics of landscape process. Based on the model, the ecological monitoring and evaluation can be developed, which can significantly improve the predictive ability of landscape ecology and then guide landscape planning design and construction. For example, wetland landscape pattern is closely related with the following ecological processes, ecological function of aquatic plants, nutrient retention, organic carbon, wetland habitat maintenance, pollutant absorption and filtration, soil erosion intercept. Revealing the control mechanism of landscape pattern on these processes can provide guidance for wetland landscape planning and design, protection and management, recovery and construction (Guo and Zhou 2002). Li et al. (2002) investigated the effect of spatial pattern on nutrient removal of a wetland landscape in the Liaohe Delta, China, using a spatial simulation model. Four scenarios have been designed to test the effect of different landscape components on nutrient removal in the reed marsh: canal density, reed area size, reed area shrinking pattern, and pumping station position. The efficiency of nutrient removal in each of these scenarios was simulated using the same spatial model especially designed for the study area. The results indicated that nutrient removal in the reed field was strongly influenced by the size of reed area, but rather weakly by canal density. The size of reed area had a much stronger effect on nutrient removal in the canals. Smaller the reed area, more efficient the nutrient removal is. Some shrinkage patterns are better than others. Moreover, the locations close to the pumping station is more efficient than more distant locations. These conclusions provide theoretical support to strategic decisions for local land use planning, and contribute to the understanding of the relationship between landscape patterns and functions (Li et al. 2002). We argue that the simulated results are believable as the model has incorporated the most important factors such as area, distance and input load, and regulated the uncertain factors, such as denitrification, sedimentation, plant up-taking, time and temperature with linear and non-linear regression models. Furthermore, the process models can help finding reasons why some of the simulation results are contradictory to initial predictions. Sometimes the predictions can also be erroneous because they are not based on experimental research.

Landscape pattern can be influenced by the vegetation habitat, so landscape pattern metrics are often used to reflect the changes of habitat. In recent years, landscape patterns with certain ecology model have been used to examine the protection of wetland habitat for living things although the related study is scare (Powel & Croke 2008). Using the patch-corridor-matrix patterns on LCM2000, Fuller et al. (2007) developed cluster analysis to the bird distribution and habitat across Britain. Results showed that scarce coastal and wetland habitats were proved to be particularly important for many birds. The study also informed the sustainable landuse for policy makers. Meanwhile, this study suggested it is applicable to use landscape ecology theory to analyze the habitat characteristics and to build models to develop and test the sustainable management of landscape for birds. Hof et al. (1999) investigated an optimization approach to determining the placement and timing of habitat protection for a rare wetland plant. The study built the model including the habitat optimization formulation after analyzing the plant population dynamics and quantifying some population indexes, variables and parameters used in the optimization model. Furthermore, the modeling results and landscape pattern metrics were expressed in an enhanced graphics of the selected study area with GIS software. Integrated many habitat factors, the graphics presents the management strategy solved by the model. The study also proved

that the spatial and temporal pattern of protected habitat was important to the plant. The model is available to some extent, although this study is clearly an exploratory effort to model the habitat protection and wetland plant pattern. Because the model included some important factors such as the indexes of swale complexes, contours within a swale complex, long term climate, variables of seeds, protocorn, area of plants, and so on. Undeniably, some weaknesses occur in the model. For example, the tenability of such a model is eroded rapidly with time as variances around expected values increase. Moreover, the assumption modal makes the plant resistant to catastrophic loss, but perhaps the plant is vulnerable to catastrophes in reality. But in generally, this study is meaningful for authors researching the habitat protection by using landscape pattern as a channel to delineate the swale complexes. And the habitat can be further quantified by optimization formulations. We consider that it is an innovation to apply landscape ecology into wetland protection, because it is not limited to describe the landscape pattern metrics but reflects the change mechanism of plant habitat. The optimization approaches are heuristic and can suggest "good" landscape arrangements rather than truly optimal layouts.

The importance of integrating spatial pattern with ecological processes has been embodied in many studies (Gamble et al. 2007; Huang et al. 2007a, b; Lett et al. 1999; Martinez & Toan 2007). Huang et al. (2007b) applied this theory into the research on biological invasion of *Spartina alterniflora* at Jiuduansha Shoals, Shanghai, China. In conjunction with RS and GIS, the authors developed a Cellular Automata (CA) model to simulate the expanding process of *S. alterniflora* for a period of eight years after being introduced to the new shoals, and studied the interactions between spatial pattern and ecosystem processes for the saltmarsh vegetation. Besides, the accuracy assessment was executed in the GIS platform using Arc/GIS software and the model could satisfactorily simulate the pattern of population dynamics of invasive and native species at a broad scale for Middle Shoal. The results have strongly supported the ecological theory of preemption as well as range expansion with simple advancing wave fronts for these two species. More important thing is that some physical or mechanical control measures have been taken based on the control strategies drawn from this study. We can argue from this study that landscape ecology emphases the study of complex biological process but it is often difficult for experimental or observational studies at larger scales due to factors such as lack of replication in landscape ecological studies, interactions between spatial and temporal dynamics, etc.(Jenerette and Wu 2001). In this condition, pattern change in conjunction with simulation modeling is a key tool for understanding the complex dynamics of ecosystems. It supplies a good means for extrapolating ecological relationship between research sites with environmental driving functions and across a range of spatial and temporal scales over which controlling factors may vary significantly. Martinez & Toan (2007) researched the relationship between flood temporal dynamics and spatial distribution of vegetation using the time series of SAR images. It showed that the ecological succession processes following a pattern of vegetation communities is fully governed by the exposition of vegetation communities to flood stress. And the process can be modeled as a function of the mean annual exposure to floods. From this instance we can argue the importance of pattern to the study of ecological process. And it is the key to the research of wetland succession dynamics and restoration of ruined wetland (Martinez & Toan 2007).

Ecotone is another important landscape pattern, and plays a unique role in ecosystem function. Obviously, wetland is a typical ecotone. Thus, the study on wetland landscape should be paid more attention to the characteristics of aquatic and terraneous transition belt. As many wetland animals are amphibious, in the planning and management of wetlands, designing the suitable aquatic and terraneous habitat and landscape pattern such as suitable matrix, patch and corridors is of great significance for the protection of amphibians (Chen and Wang 2002). Ecotone is characterized by obvious edge effect. For example, Walker et al. noticed that number of exotic bird species was higher in ecotones than in surrounding environments (Wilson & Steel, 2003). But Lek-Ang et al. (2007) reported a reversed result from studying the structure of Collembolan communities in a peat bog surrounded by forest in the French Pyrenees. They pointed out the ecotone was not necessary to the most species-rich zone. Perhaps the above difference in ecotone is caused by the different study scale, such as individual, community or landscape and region scale. Another reason is probably linked to habitat instability and associated disequilibrium, which is known to favor opportunistic species. Another important ecological function of land-water ecotone is the retention capacity to the terrigenous nutrients such as phosphorus, nitrogen, which it is key to water ecosystems remain self-regulation. For instance, Yin et al. (1999) researched the retention capacity of Phosphorus and Nitrogen in land-water ecotone soil in lake Baiyangdian. The results from column experiments suggested that the soil have higher environmental capacity. The amount of phosphorus absorption was 24 times large as that of taken by annual reed harvesting. This research is great benefit to better utilizing local ecotone and designing the planning project that aims to water eutrophication control (Yin et al. 1999)

Application of scale and hierarchy theory to research on wetlands

Landscape is a space mosaic of various landscape components and is characterized by hierarchy. The components at certain level are constrained by holistic environment at a higher level as well as the lives at a lower level. Hierarchy theory is the basis of landscape framework (Xiao et al. 1997; Goebel et al. 2006). How to choose a suitable geospatial scale to solve landscape ecology issues is one of the core issues concerned by geographers (Liu and Li 2002; Zedler 2000). The conservation and sustainable use of wetland relates to spatial scale to some degree. The theory of scale and hierarchy is important for wetland study, especially the valley wetlands and stormwater wetlands.

For instance, studies indicates that wetland stormwater treatment areas (WSTAs) can provide the services of water storage and peak-flow attenuation (Ogawa and Male 1986; Delaney 1995), nutrient cycling and burial (Richardson 1985; Reddy et al. 1993), metal sequestration (Thurston 1999; Odum et al. 2000), sediment setting (Kadlec & Knight 1996) and breakdown of organic compounds (Nix et al. 1994; Kinght et al. 1999). Stormwater management is typically achieved in an incremental form (i.e., on a site-by-site basis) (Emerson et al. 2005; Powell et al.

2008), with little attention paid to larger scale hydrologic organization that exists in all landscapes shaped by water. The common result is watersheds that lack the characteristic hierarchical hydrologic convergence found in undeveloped basins (Ogawa & Male 1986). However, watershed scale planning (USEPA/USDA 1998) warranted explicit attention to the larger scale patterns. Previous work exploring the role of wetland size and location came to different conclusion about the wetlands treatment function (Loucks 1990; Van der Valk 1992; Ogawa & Male 1986). And all the results are right just depending on the scale studied. That is to say the treatment function is scale dependant: small wetlands sequester P, medium wetlands capture sediments and large wetlands capture sediments and attenuate water flows, based on area requirements for meeting target outflow criteria (Cohen & Brown 2007).

The previous study indicated the importance of wetland scale and hierarchy. After examining hydrologic convergence patterns found in watersheds and the synergistic effects of multiple size of WSTAs on watershed discharge, Cohen and Brown (2007) put forward the hypothesis that wetlands are hierarchically organized in undisturbed landscapes to maximize pulse attenuation of water, nutrients or sediments. Basing on the hypothesis the authors emulated the observed spatial hierarchy for WSTAs to improve the stormwater discharge properties and explore the role of hierarchy network in the design and management of stormwater collection and treatment systems in human dominating, low-relief watersheds. They also developed the study using a theoretical process-based systems simulation model. One of the results suggested that different wetland sizes provided different treatment roles. For water, large wetlands retained the major (53%), while small wetlands with flashy hydro-graphs retained the minor (5%). For phosphorus, medium wetlands retained 65% the sediment load while small wetlands retained 30% of the sediment load despite of their small total area. Results indicated that other parameters such as flow attenuation, pollutant removal and overall retention rates are all scale and hierarchy dependent. Take the annual retention rates for an example, the network approach retains water longer than the baseline scenario resulting in reduced outflows (less 31% flow), and concomitant reduction in sediments (36%) and phosphorus (27%). In recent years, the numerous models that have been developed for predicting the hydrologic and biogeochemical behavior of wetland systems (Wong and Geiger 1997; Raghunantan et al. 2001; Musacchio and Grant 2002; Zhang and Mitsch 2005), generally adopt similar levels of process specificity with similar system-scale accuracy level, and could be adapted for use as basin-scale planning tools with integration of network flow convergence. In comparison with an incremental approach wherein hierarchical hydrologic convergence is ignored, different scale organization of treatment systems makes the most substantial difference in predicted wetlands quality.

Goebel et al. (2006) quantified the hierarchical relationships among different physiographic systems (ground moraine, outwash plain), valley segments (constrained, unconstrained), valley floor landforms (floodplains, terraces, valley wall, and adjacent uplands), and riparian plant communities in a large watershed located in northeastern Wisconsin, USA. The canonical correspondence analyses (CCA) of individual valley types indicated that ground-flora vegetation was related strongly to hierarchical landscape properties, including valley type and the transverse geomorphic structure of the stream valley. The results indicated that the variation in riparian plant community characteristics can be explained using a nested, hierarchical landscape framework to organize and group different riparian settings based on the underlying geomorphic process shaping stream valleys. Based on the above results, the authors suggested that riparian management zones (RMZs) designed to maintain riparian function should be variable in width rather than fixed, encompassing variation in valley floor landforms and valley walls, regardless of the physiographic system. This is an innovative research as few studies use a hierarchical approach to quantify the effects of longitudinal and transverse geomorphic structure on riparian plant communities (IIhardt et al. 2000).

Hierarchy theory provides the conceptual basis for the approach to understanding the wetlands function, wetlands plant pattern, wetlands protection and management and multi-scale environmental factors. Hierarchy theory predicts that the upper hierarchy levels constrain and mediate the dynamics of lower hierarchical levels. Therefore hierarchy approach is valuable for the study of wetlands at multiple spatial scales within a regional context and temporal scales over years.

Results and Discussion

Landscape ecology has being established rapidly in the past few decades and developed by introducing RS, GIS and GPS technology. It has resolved many actual issues of wetland protection, planning and management. However, as mentioned by Wu and Hobbs (2007), diversification in perspectives and approaches has apparently caused some concerns with the "identity" of the field in recent years. Embodying in the application to wetlands, we mention the following aspects:

Firstly, we need improve our ability to collect and interpret spatial data and further ensure the effective metrics are developed which aid in this interpretation. Take the landscape pattern metrics for example. Parsimonious measures of spatial patterns can provide useful descriptions of heterogeneous landscapes, allowing the consequences of landscape change to be quantified and compared in time and space. A multitude of pattern metrics have been developed to satisfy this critical need. Some have been referred as the above. However, the studies on how these metrics can be used to inference the underlying ecological processes are scarce. This raises the query about whether the effect of landscape pattern on ecological process can be measured well by these metrics. Moreover, a little work has been done in the correlation between these metrics and the underlying ecosystem function. A study by Li et al. (2005) indicated that 68% of the statistical relationships between different landscape structures were highly inconsistent and sometimes ambiguous for differences in dispersal behavior. Thus we should validate firstly the consistency between some landscape metrics and wetland function and process before studying the impact of landscape pattern on wetland function and process. The dispersal success on fractal landscapes indicates that the gap structure is a more important determinant of dispersal than patch structure. Thus gap structure and patch structure should be paid attention in researching the wetland landscape structure and function (Li et al. 2005).

Secondly, various methods can be used in analyzing landscape

pattern and ecological process, such as the method of mathematic statistics and landscape model, especially in the representative of North American schools of thought in Landscape Ecology (Li et al. 2005; Huang et al. 2007b; Lek-Ang 2007; Zhang & Mitsch 2005). Furthermore some authors have developed constructible and solvable spatial optimization models that are important for studying multi-scale wetlands functions, complex interactions between individuals, species or communities and further for the wetland management and protection (Hof et al. 1999). Another major school of thought in landscape ecology that has been recognized widely is European approach. But the European approach is more holistic and humanistic compared with the North American approach that is more biophysical and analytical. This enlightens us to increase the synergy between the two schools of thought. We think multi-perspectives and approaches can help the research of wetlands.

Thirdly, the theories of landscape ecology are not separated but integrated. For instance, scale and heterogeneity are two key concepts in landscape ecology which are inherently related to each other. Wetland patches and gradients are manifested by heterogeneity, which are intertwined across multiple scales. Landscape pattern is meaningful only at certain scales. Besides, landscape ecology is a cross-disciplinary. Thus the study on wetland landscape ecology should permeate all the theories and the concepts of holism. However, the wetland spatial patterns, causes, and effects of ecosystem function across landscapes have received less emphasis compared with the focus on species, population, communities (Hof et al. 1999; Huang et al. 2007 a, b). Therefore, integration of ecosystem and landscape ecology is necessary and it can provide wider insights into wetlands landscape function.

From the above, we can generalize that landscape ecology has given wetland research a new vigor and plays an enlightening and guiding function on the comprehensive research of wetlands at multi-scales. The methods and theories of landscape ecology have permeated many aspects of wetland research such as wetland landscape pattern, ecology process (hydrology and biogeochemical cycle process) function, planning and management.

In conclusion, we summarize the characteristics and hot spots of wetland research: the quantitative research of ecology process and function; the integrated research of interaction between wetlands and peripheral environment; the function of retention filtration; the research of larger scale ecology process; the research of relationship between wetland pattern dominated by diversity and maintenance of biology habitat and species; comprehensive application of biological monitoring, mathematical methods, RS, GIS, GPS and computer technology.

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